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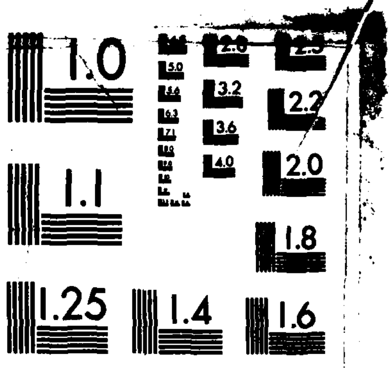

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NAVAL MEDICAL RESEARCH INSTITUTE
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NMRI 85-17

STATISTICALLY BASED DECOMPRESSION TABLES

II. EQUAL RISK AIR DIVING DECOMPRESSION SCHEDULES

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19 ABSTRACT (Continue on reverse if necessary and identify by block number)

Several sets of equal risk air decompression tables were calculated using a new methodology. Empirical decompression risk models were used to predict the probability of decompression sickness (DCS) for a given pressure exposure. These probabilistic models, earlier shown to have a considerable ability to separate tabulated experimental air dives according to DCS risk, were used to choose decompression schedules with an acceptable risk. The levels of risk used were 1% and 5% for standard air dives with an additional set of 0.5% no-decompression limits.

As the new method calculates risk according to an integral over the dive and postdive period, many possible decompression schemes will have the same risk. The best schedules are defined as those requiring minimal total decompression time for the specified risk and subject to operational constraints. The constraints used here are decompression stops at even 10-ft intervals of depth for whole minutes. An algorithm was developed to obtain

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schedules in a partially optimal manner. The methodology can be used directly to produce tables for other operational constraints or risk levels. Because of the known limitations of source data and risk models, these tables represent considerable extrapolation from known procedures and should not be considered for use without testing.

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BACKGROUND

The first report of this series (Weathersby et al., 1985) presented an evaluation of several empirical decompression models conducted to examine their precision in matching the known outcome of more than 1,700 reported dives. Those empirical models were a break with previous methods because a frankly probabilistic formalism was adopted and because a statistical evaluation of model success was conducted. The models are quite empirical because no specific knowledge is presumed regarding mechanisms of bubble formation, growth, etc. Nevertheless, the models were shown to be successful in summarizing a large number of decompression trials and in separating dives according to their risk of DCS. The statistical models did not consider variations in diver workload, environment (e.g., wet vs. dry), or acclimatization. The success in that endeavor has encouraged us to produce a new set of air decompression tables characterized by an equal chance of DCS. We feel these tables should be a useful step forward, although they are specifically not a final version.

MODELS AND PARAMETERS USED

The candidate models are described at length in the previous report, so only a short review is presented here. Evaluation of the safety of a dive is accomplished by relating the entire dive profile to the probability of DCS by a "risk function":

$$p(DCS) = 1.0 - \exp\left(-\int r \, dt \right) \qquad [1]$$

Here, r is one of several measures of instantaneous risk that is integrated over the course of a dive and postdive period.

The first two versions of r examined previously (Models 1 and 2) do not describe a large number of dives very well and will not be pursued here.

Four other versions (Models 3-6) did enjoy a measure of success. The first of this group considers two "tissdes" to be followed in parallel:

Model 3: $r_3 = r_{3A} + r_{3B}$, where

$r_{3A} = AA\ (\ Ptis_A - Pamb\ )\ /\ Pamb$

$Ptis_A$ by monoexponential, time constant = TA

$r_{3B} = AB\ (\ Ptis_B - Pamb\ )\ /\ Pamb$

$Ptis_B$ by monoexponential, time constant = TB

4 parameters: AA, TA, AB, TB [2]

The statistical sense of this model is that the outcome of no DCS is the joint probability of no DCS in both "tissues." In each of the "tissues" a computed inert gas partial pressure in tissue, Ptis, is compared to the current ambient pressure, Pamb. The metabolic gases O_2, CO_2 and H_2O will be ignored. Whenever Ptis is less than Pamb, r will be set to zero in keeping with the notion that DCS is somehow precipitated by a supersaturation of inert gas. The risk in each "tissue" here is simply proportional to the supersaturation with a proportionality parameter A. The appearance of Pamb in the denominator follows from our work with saturation-excursion data in which we showed that a significant decrease of DCS risk occurred if an equal supersaturation was created at deeper depth (Weathersby, Homer, and Flynn, 1984). In all models used in the present work, this denominator will be used even though it was not shown necessary for shallow air diving. This two "tissue" model can also have a threshold parameter added:

Model 4: $r_4 = r_{4A} + r_{4B}$, where

$r_{4A} = AA\ (\ Ptis_A - Pamb - PTHR\ )\ /\ Pamb$

$Ptis_A$ by monoexponential, time constant = TA

$r_{4B} = AB\ (\ Ptis_B - Pamb - PTHR\ )\ /\ Pamb$

$Ptis_B$ by monoexponential, time constant = TB

5 parameters: AA, TA, AB, TB, PTHR [3]

The sense of PTHR is an absolutely safe excess partial pressure of nitrogen that can be sustained indefinitely with no risk of DCS. Instead of the "two-tissue" model it is possible to use an alternative model of gas exchange kinetics in a single tissue. That description uses a more complex gas residence time function (rtf) to describe tissue exchange (Weathersby et al., 1979). The rtf is a multiexponential description of gas exchange in a single tissue with three kinetic parameters rather than the one of a single exponential:

Model 5: r_5 = A (Ptis - Pamb) / Pamb

Ptis by 2 exponentials, time constants = T1 and T 2

Fraction of rtf by T1 is W1, fraction of rtf by T2 is 1-W1

4 parameters: A, T1, T2, W1 [4]

A threshold parameter can also be defined for the two exponential gas exchange model (labeled Model 6 in Report I). In practice, we did not find that the addition of a finite threshold was justified statistically for most data sets, and Model 6 was not considered for most of the development of new tables.

In the previous report these models were applied to various decompression data sets obtained during the period 1950 to 1970 in several naval laboratories. Different estimates of the model parameters were obtained from each data set, although it was shown that the data could nearly be treated as a single source. For most purposes of constructing new tables, only the parameters from the largest data set (designated ABCD) will be used. That set contains over 1,700 individual dives of a large variety, and we expect that the variety will make extrapolation to untested dives somewhat more reliable than the use of a smaller set. Three models (Models 3-5) had nearly equivalent success in describing those data. Table 1 presents the parameters of those models and provides one additional set of parameters used in a

TABLE 1

Parameters Estimated From Decompression Data*

Data Set ABCD			Data Set ABC
Model 3	Model 4	Model 5	Model 5
TA = 2.43	TA = 6.17	T1 = 3.73	T1 = 1.5
AA = $3.19 \cdot 10^{-3}$	AA = $3.16 \cdot 10^{-3}$	W1 = 0.974	W1 = 0.990
TB = 383	TB = 260	T2 = 265	T2 = 265
AB = $2.73 \cdot 10^{-3}$	AB = $7.63 \cdot 10^{-3}$	A = $1.06 \cdot 10^{-2}$	A = $1.18 \cdot 10^{-2}$
	PTHR = 5.03		

*Refer to Reference 10.

The time constants (TA, TB, T1, T2) are in units of minutes; the scale parameters (A, AA, AB) are in min^{-1}; PTHR is in fsw; and W1 is dimensionless.

subsequent example. Choice of a model and parameter set is sufficient to evaluate p(DCS) for any dive whether or not it is actually performed. As no clear choice of a single model could be made on the basis of fitting Data Set ABCD, all three will be examined further.

CHOICE OF NO-DECOMPRESSION LIMITS

Searching for sufficiently safe no-decompression dives is straightforward: one constructs a depth-time profile with the anticipated dive and calculates p(DCS) according to one of the models. This has been done for a number of times at the depths of interest. Sample results are shown in Figs. 1 and 2. For both 60 and 120 ft dives, the figures are types of dose-response functions where the dose is time at depth. For the times near those currently accepted, i.e. 60 min at 60 ft and 15 min at 120 ft (U.S. Navy Diving Manual, 1973), the models agree within about a factor of two on the level of safety. The models diverge, however, on predictions of how short a dive must be for increased safety. The "two tissue" models (Models 3 and 4) have substantial plateau regions with no change in safety relative to time. These regions correspond to decompression after the first time constant has reached its maximum effect but before the second time constant (TB) has raised the PN_2 above one atmosphere. Because Model 5 is a different kinetic model, its dose-response function has a smooth character throughout.

Curves such as Figs. 1 and 2 can be read to obtain the bottom time limit for an arbitrary degree of safety. Results for three levels of safety are tabulated in Appendix 1. For each of the three models, times for 0.5, 1.0, and 5.0% probabilities of DCS are provided. The 0.5% figure is included should limits be desired that are safe enough to justify some of the extraordinary confidence some people place in such tabulations. Reading down any column in Appendix 1 gives the shortening of bottom time for an increase

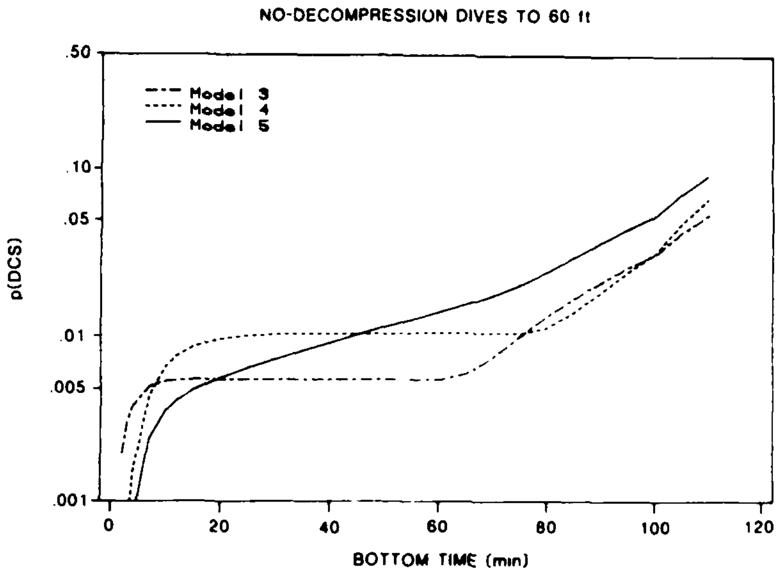

Fig. 1. Probability of DCS after dives to 60 ft for various bottom times followed by direct ascent to the surface. Results are plotted for three different models and parameters from Data Set ABCD.

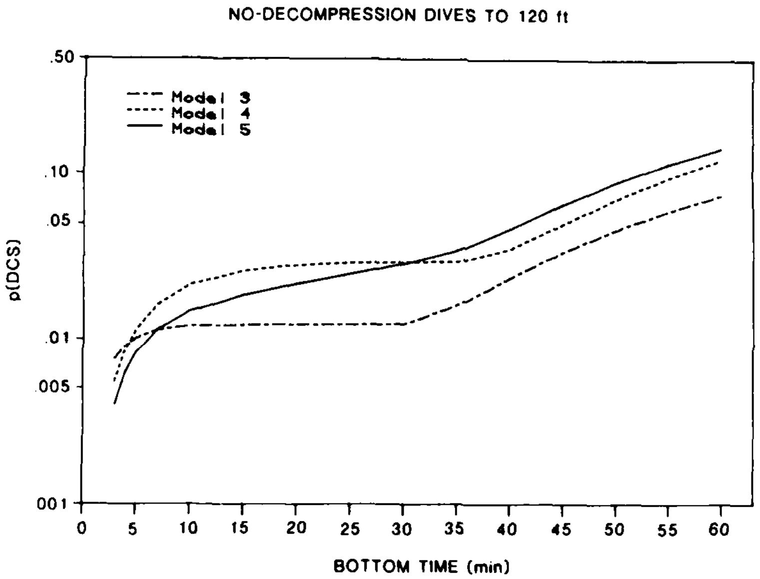

Fig. 2. Probability of DCS after dives to 120 ft for various bottom times followed by direct ascent to the surface. Results are plotted for three different models and parameters from Data Set ABCD.

TABLE 4

Comparison of 1% DCS Tables by Three Models

Model	Stop Time (min) 100	90	80	70	60	50	40	30	20	10	Total
Depth = 60 ft, Bottom Time = 180 min											
3							1	2	5	809	818:00
4								3	21	244	269:00
5								2	39	341	383:00
Depth = 150 ft, Bottom Time = 60 min											
3		1	1	1	1	1	2	2	5	850	866:30
4			1	4	2	3	3	4	79	254	352:30
5						1	2	5	64	341	414:30
Depth = 270 ft, Bottom Time = 20 min											
3	3	1	1	1	1	2	2	2	4	568	589:30
4	7	2	2	2	2	3	3	4	5	201	235:30
5					1	1	1	3	6	164	180:30

In all cases, the maximum decompression stop depth considered was 100 ft. For the 270/20 schedules of Models 3 and 4, a conceivable increase in efficiency is possible with deeper stops.

The internal search minima of 112 and 495 min total times are used in log-linear interpolation to choose 415 min total time for the next internal search. Searches at 413 and 412 min were also performed before a final schedule with p(DCS) = 0.010056 and a stop time distribution of 1-2-5-63-341 was accepted. In the entire search almost 300 specific decompression profiles were examined, and the results were available within a few minutes. For the production of final tables, if the final results included any time at the deepest stop, the whole process would be repeated with allowance for an extra deep decompression stop.

FINAL TABLES

The quicker search just described was used to construct the final decompression tables reported here. Models 3, 4 and 5 were all examined to find acceptable schedules, but as expected the predicted schedules are not very consistent across models. Three examples of model dependence are presented in Table 4: a shallow, long dive: a dive intermediate in depth and time; and a deep, short dive. The most obvious difference is the distribution of stops: Models 3 and 4 have a short time constant that does not allow a long initial "first pull" toward the surface. The shortness of the time constant, however, requires only a few minutes at the deeper stops for that "fast tissue" to recover. Model 5 specifies a faster return toward the surface with nearly all the decompression time at 20 and 10 ft. Total decompression times required by the models appear different, but agreement in these and most other cases is 20-100%; this is close considering the extrapolation involved. We are certainly not in a position of confidence to say whether 4, 5, or 9 h is actually required for 1% p(DCS) after deep and long dives.

vs. total time. Then the internal search is initiated. The 112 min decompression is assigned in its entirety to the 10 ft stop. Examination of how 112/(2 x 5) = 11 min times would change p(DCS) if used at the other stops leads to no improvement: all time at 10 ft is the optimum at a time increment of 11 min. Calculation of gradients using 5 min time increments also results in no improvement; the best allocation is still 112 min at 10 ft. When step size is halved again to 2 min, gradients tend toward increased safety with some time at 30 and 20 min, the optimum is 2 x 2 min at both depths of 30 and 20 ft, and the balance is 104 min at 10 ft. The gradient search at 1 min increments provides an apparent minimum risk at a 1-5-7-99 time distribution. Examining all 1 min changes from this combination produces a series of small improvements that are optimal at a 1-3-8-100 time distribution for the 40-30-20-10 ft stops.

For the first external search the 0 and 112 min results were used to project the total time required to reach a p(DCS) of 0.01. That log-linear extrapolation predicts 495 min. The next several lines in Table 3 summarize the internal search with 495 min total decompression time. The first time increment examined is 495/(2 x 5) = 49 min; a 49 min coarseness minimum is determined as 98 min at 20 ft and the remainder of time at 10 ft. The gradients lead to (minimum) 24 min stops at 50, 40, and 30 ft when the next time increment of 49/2 = 24 min is used. The optimum 24 min schedule of a 24-24-24-122-301 time distribution is used to start the examination of 12 min increments, which in turn leads to 6, 3, and 1 min gradient searches. The final entry at 495 min is the final answer to the internal search after the 1 min local search is performed with the 1-3-3-109-379 time distribution gradient minimum that provides the point of 495 min, 0.52% risk in Fig. 6. Because 495 min results is a p(DCS) less than desired, the search continues.

TABLE 3

Partial Search in 150/60 Evaluation

Total Time	Time Grid	p(DCS)	Time (min) at Decompression Stops 50	40	30	20	10 (ft)
0	0	0.2589	0	0	0	0	0
112	11	0.1364	0	0	0	0	112
112	5	0.1364	0	0	0	0	112
112	2	0.1248	0	0	4	4	104
112	1	0.1238	0	1	5	7	99
112	1	0.1234	0	1	3	8	100
495	49	0.01454	0	0	0	98	397
495	24	0.01346	24	24	24	122	301
495	12	0.00782	12	12	12	110	349
495	6	0.00609	6	6	6	104	373
495	3	0.00541	3	3	3	109	377
495	1	0.00533	1	3	3	109	379
495	1	0.00520	1	2	5	107	380
415	41	0.01865	0	0	0	82	333

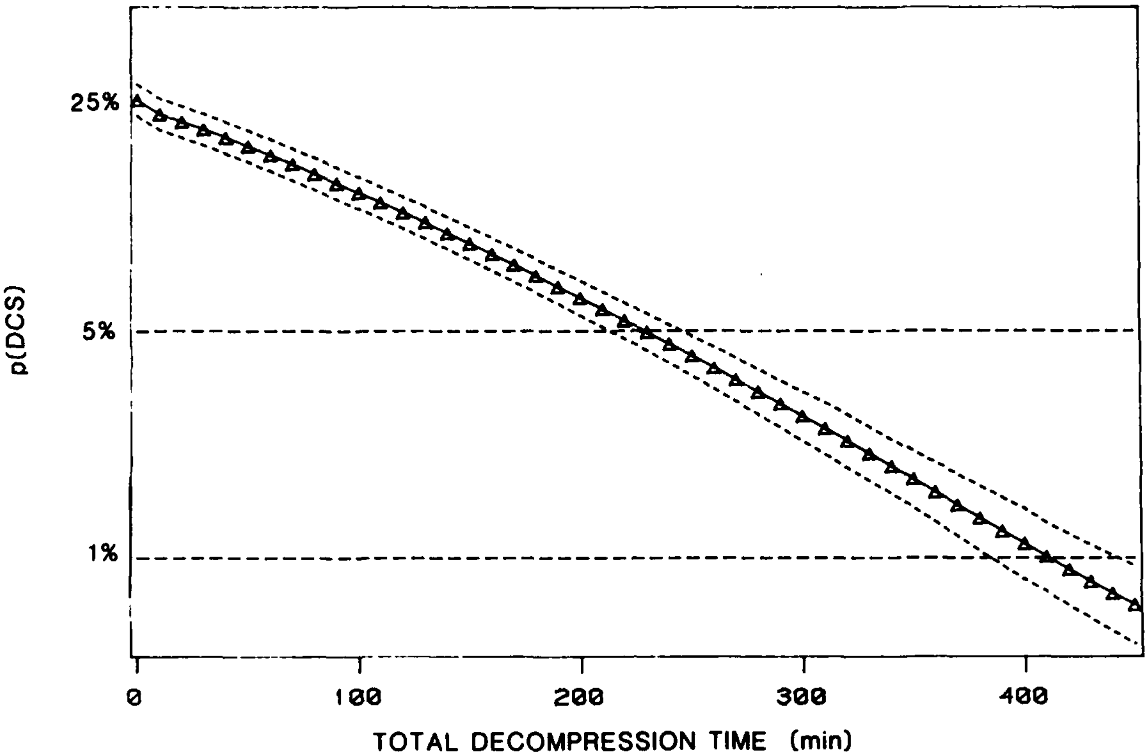

Fig. 6. Semi-logarithmic plot of p(DCS) vs. total decompression time after a 150 ft/60 min dive. Decompression time is allowed in 1 min increments during stops at 50, 40, 30, 20, and 10 ft. The dotted lines bordering the line of triangles are propagated 1 SE uncertainties in calculated probabilities using Model 5 and Data Set ABCD. At each total decompression time the distribution was optimized by the internal search described in the text.

time is chosen by dividing the total decompression time by twice the number of stops and truncating to a whole number of minutes. A modified gradient method is then employed to explore the change in p(DCS) that results from adding 1 min to the other depth stops. Times are adjusted by the step size and the gradient search is continued until a previous optimum combination is duplicated. At that point, step size is halved and the process starts again from the optimum until the step size falls below 1 min. Now the smoothness assumption is invoked: times are changed in tandem by 1 min increments from the current combination until no better combination can be found within 1 min of the optimum. That optimum is declared the best use of the current total decompression time.

The external search for total decompression time assumes that improvements on the logarithm of p(DCS) are nearly a linear function of total decompression time. (As shown in Fig. 6, such relations can be accurate.) In the present algorithm the line of extrapolation or interpolation uses the two total times (evaluated for minimum risk as described in the preceding paragraph) nearest the specified risk for the desired tables. The search for optimum total time stops if the desired risk is obtained within a specified tolerance, or if no decompression stops are required, or if a 1 min change in total time spans the specified risk. The algorithm agrees with the exhaustive search approach in the few test cases run for comparison.

For example, the partial history of the search path in the 150 ft/60 min dive is shown in Table 3 using Model 5 and Data Set ABCD. Initial specifications were: a p(DCS) of 1.0% with a tolerence of 0.01%; five decompression stops at 50, 40, 30, 20, 10 ft; and an initial time of 112 min, the current standard USN time.

The first entry is calculation of risk for the no-decompression case. This will provide one point (at 0 min and 25.9% risk) on the plot of p(DCS)

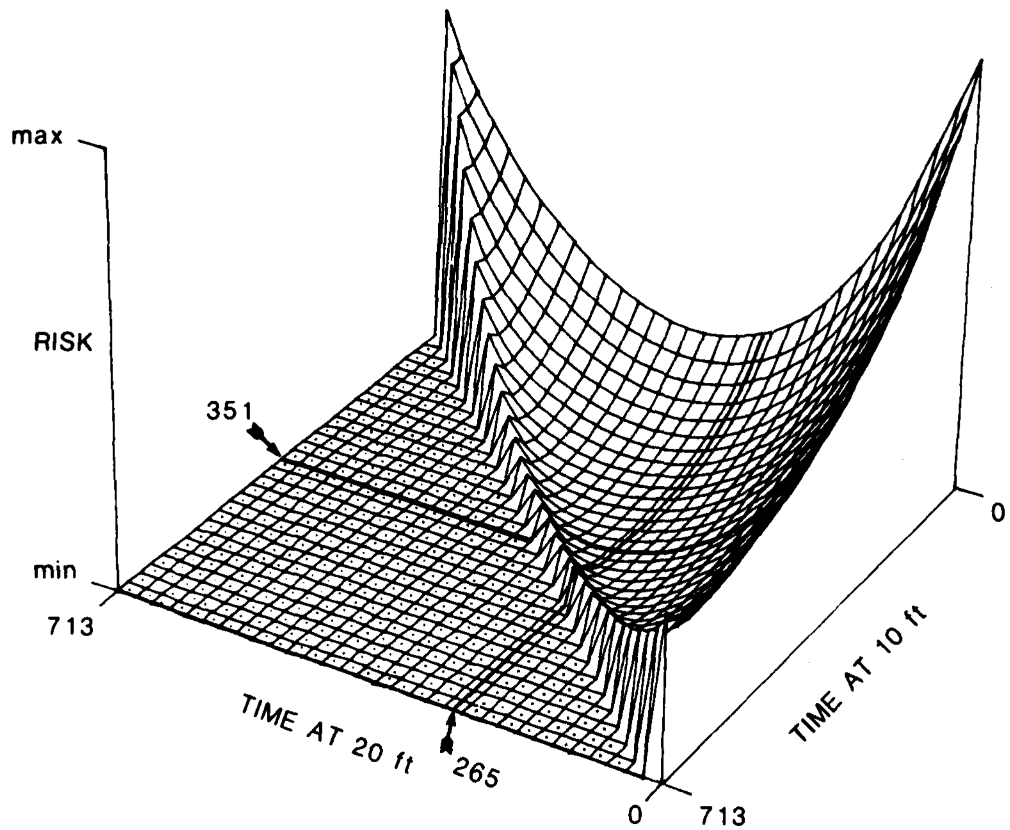

Fig. 5. Risk surface of possible decompression schedules using Model 5 and parameters from Data Set ABCD. Dive profile was 50 ft/720 min with a total decompression time of 713 min allowed in 1 min increments at stop depths of 30, 20, and 10 ft. The optimum distribution is the minimum of the risk surface found at 351 min at 10 ft, 265 min at 20 ft, and 97 min at 30 ft. The minimum risk is 1% DCS and the maximum is 25%. The grid areas with dots are not permissible combinations because total decompression time exceeds 713 min.

OPTIMIZING SEARCH PROCEDURE[1]

Continuation of the previous procedure to examine possible decompression schedules with as little as 1 min time intervals, or including many stops, quickly becomes impractical even with appreciable computer resources. Several shortcut schemes were explored to arrive at nearly optimal schedules without a completely exhaustive search. It must be stressed that complete global optimization (i.e., discovery of the absolutely best time distribution) cannot be guaranteed by any of the shortcut methods because the mathematical properties of the risk models have not been fully explored.

A method was evolved that produces tables to 1 min intervals in one-one hundredth to one-one thousandth the time of a complete search. The flow of that algorithm is shown in Appendix 2. The search technique has two phases: an internal search to find the minimum risk for a given amount of decompression time and number of stops and an external search to find the decompression time required to meet the specified p(DCS).

The internal search assumes the global smoothness of the risk surface. One risk surface is plotted in Fig. 5. In this three-dimensional presentation a prospective decompression with three stops is examined for its safety. Time at two of the stops is represented by the X-Y axes, and because total time is fixed, the third stop is specified automatically. Note the minimum risk at a particular time combination and note the absence of other minima in the surface. Smoothness here indicates that the combination of stop times resulting in the safest decompression is surrounded by other stop time combinations that are gradually more severe. The search begins by allocating all of the decompression time to the shallowest stop. An initial step size of

[1]This section is included to document the source of enclosed decompression tables. We appreciate its limited appeal to most readers.

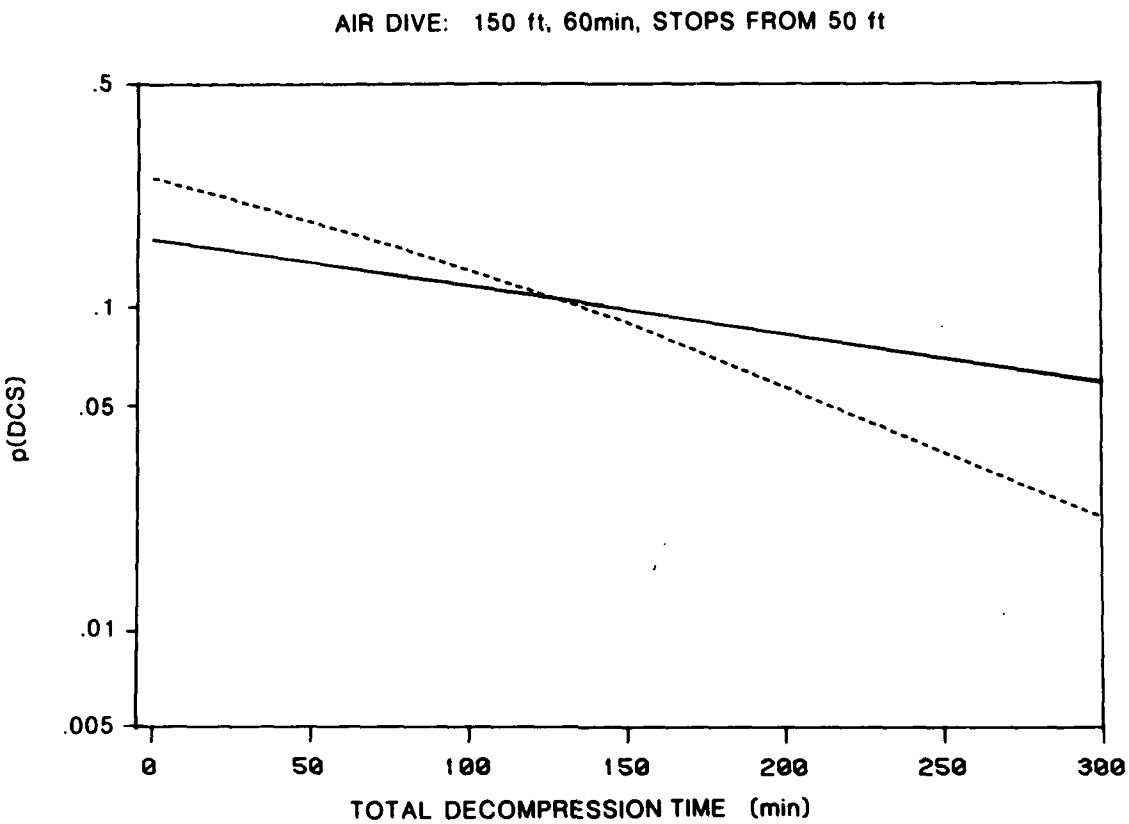

Fig. 4. Effect of total decompression time on the probability of DCS after a 150 ft/60 min dive. Both Models 3 and 5 were used with parameters from Data Set ABC. Decompression time was distributed over stops at 50, 40, 30, 20, and 10 ft using time increments of about 1/16 of the total decompression time.

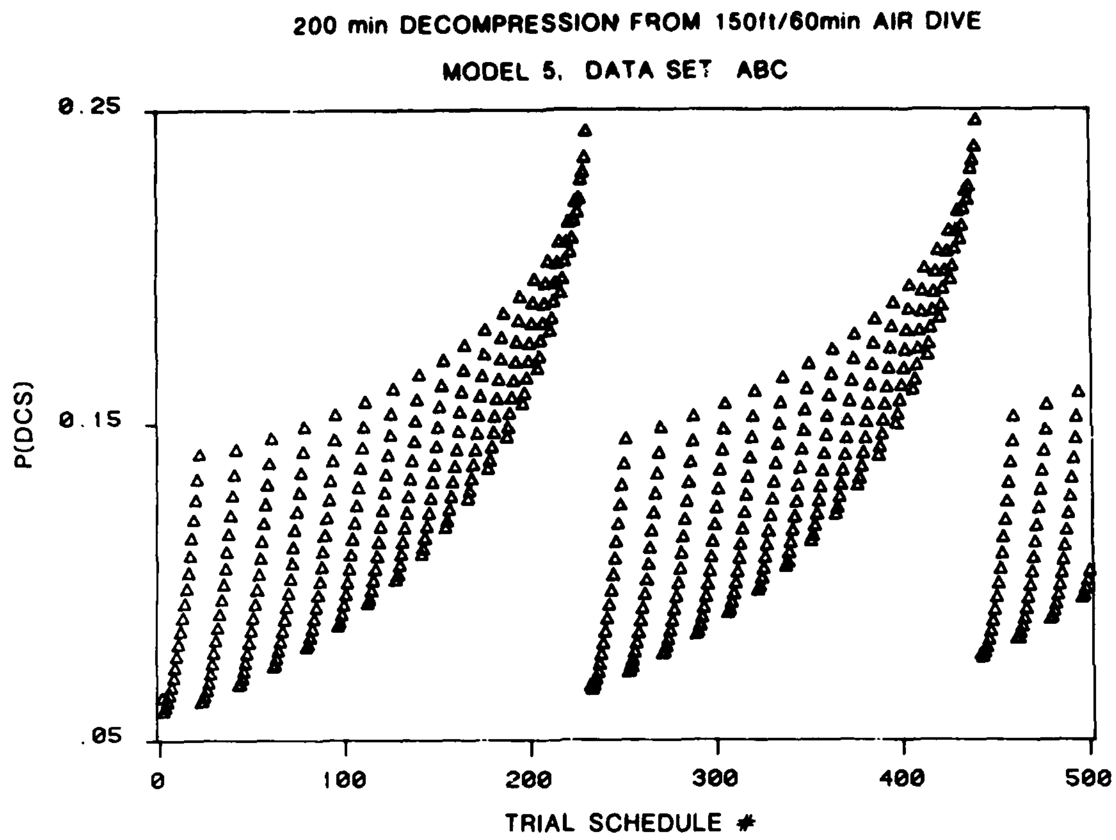

Fig. 3. Exhaustive search for minimum probability of DCS after a 150 ft/60 min dive with 200 min of decompression distributed over decompression stops at 50, 40, 30, 20, and 10 ft. All 10,626 possible combinations with 10 min increments were examined; the first 502 are plotted here.

partially shown in Fig. 3. The range in predicted p(DCS) is 5.9-44.7% with many schedules indicating the same intermediate safety. The best choice tested was #2: 10 min at 20 fsw with a rest at 10 ft. The worst was 200 min at 50 ft on trial schedule #10,626.

The minimum time increment can be reduced to search for greater safety with the same total decompression time. If the same search is performed but time is cut into 5 min segments instead of 10 min, the number of possible combinations increases to more than 500,000. At the end of that search, we find the safest combination is 5 min at 20 ft and 195 min at 10 ft with a predicted DCS risk of 5.91%. This provides one data point for a plot of p(DCS) vs. total decompression time.

The next step is to repeat this process for different amounts of total decompression time and observe the effect of total time on safety. For the same 150 ft/60 min dive, results are shown in Fig. 4. As expected, for Models 3 and 5 decompression is safer when it is longer. The two models disagree, however, on how much safety another 10 min of decompression can provide, that is, they have different slopes on a plot like that of Fig. 4. The models predict nearly the same p(DCS) around total decompression times of 100 min, the range at which experiments were performed. All models also agree that 0.1% incidence DCS cannot be obtained without an overnight decompression.

Performing an exhaustive search at a single total decompression time and then changing total time and repeating decompression to approach a specified level of p(DCS) is a sure but slow method. Computational time can exceed one day on a moderate size computer (DEC PDP 11/70). A more efficient search process is desirable.

TABLE 2

Possible Decompression Schedules for 150 ft/60 min Dive
With Total 200 min Decompression

Schedule	p(DCS)	Time (min) at Stops 50	40	30	20	10 (ft)
1	0.063709	0	0	0	0	200
2	0.059382	0	0	0	10	190
3	0.060698	0	0	0	20	180
4	0.062436	0	0	0	30	170
5	0.064578	0	0	0	40	160
:						
41	0.142262	0	0	10	190	0
42	0.067752	0	0	20	0	180
:						
350	0.169124	0	10	60	130	0
351	0.113051	0	10	70	0	120
:						
10,626	0.446521	200	0	0	0	0

Time increments of 10 min were used throughout.

for the same dive can have the same degree of safety. To choose the best schedule it is necessary to consider all applicable constraints and define an optimization rule. The major constraints for this report are 1) that decompression proceed according to 10 ft increment decompression stops and 2) that stop times be whole numbers of minutes and ascent between stops proceed at a rate of 60 ft/min. The optimization rule is a combination of maximizing safety by minimizing p(DCS) and minimizing total decompression time. We therefore define the optimum decompression schedule as one that just meets the specified level of safety yet specifies minimum total decompression time.

It is not possible to examine the infinite number of ways to decompress a diver after even one specific exposure. We can, however, examine a rather large number. For example, consider a dive to 150 ft for 60 min using Model 5 with parameters from Data Set ABC. According to Appendix 3 of report I, it appears that the present practice will produce approximately a 14% incidence of DCS. Next, we speculate about a possibly safer total decompresison time, such as 200 min instead of the 112 min in the current USN Diving Manual. According to Model 5 and the parameters given above for Data Set ABC, the tissue pN_2 immediately before decompression is 50.5 fswg. From this calculation, there appears to be no benefit in considering a decompression stop deeper than 50 ft, but we still have to decide where to apportion the 200 min total time among the 50, 40, 30, 20, and 10 ft stops. The number of possible stop time combinations is astronomical if we allow possible changes of 1 min. As a cruder approximation, consider only the 10 min increments. The candidate decompression schedules to be examined are shown in Table 2.

Each of these 10,626 prospective schedules can then be evaluated for DCS risk using one of the models that was successful in describing the data. The results of that exercise with Model 5 and the parameters for Data set ABC are

of 10 ft in bottom depth. The plateau effect seen in Figs. 1 and 2 produces some abrupt changes in this tabulation, such as those between 50 and 60 ft for 0.5% DCS in Model 3. Again, Model 5 is somewhat smoother. When less than 1.5 min at the full bottom depth fulfills the chosen degree of safety, Appendix I has no entry.

As discussed in the previous report, models similar in their ability (by maximum likelihood) to describe a data set should be similar in their predictions of dive safety in the region for which data are available; however, models will extrapolate differently. The process of estimating safety in areas of 0.1-5% p(DCS) are essentially extrapolations because the previous data examined were from experimental dives that had 5% or greater incidence of bends. Deviations as seen in the figures and Appendix 1 are therefore not surprising. Because of its smooth features we now adopt a preference for Model 5, although we have no proof of its superior extrapolation. Agreement between models is rather good, except where Models 3 and 4 approach a plateau. For deeper depths the estimated times for 1% p(DCS) are close to the present USN limits (U.S. Navy Diving Manual, 1973), but times for shallower depths are much shorter than allowed currently. This observation is consistent with our previous finding that overall USN tables are safer for short dives than long dives. We note that 135 no-decompression dives of the deep and short variety recently conducted in Canada with no cases of DCS were longer than present USN limits, but between our predictions of 1% and 5% p(DCS) (Nishi et al., 1982). That report shows some degree of safety in deep but short dives, yet it has insufficient numbers to decide on which side of the 1% risk line the dives reside.

EXHAUSTIVE SEARCH PROCEDURE

Because all models used here evaluate safety as an integration of all events during and after a dive, an infinite number of decompression schemes

One model was chosen for the final tabulated schedules that appear in Appendices 3 and 4. The choice was Model 5 for two reasons: 1) This model had a smoother dose-response prediction for the no-decompression calculations shown in Figs. 1 and 2; and 2) it is a kinetic model that has a stronger basis in experimental physiology (Weathersby et al., 1981). The latter statement must be tempered by the realization that the parameters of Model 5 demanded by the data (Weathersby et al., in press) are quite different from those found in direct gas exchange experiments (Weathersby et al., 1981). It should also be noted that the other models have the characteristic of extending decompression time at rather deep decompression stops (Table 4). Several recurring theoretical ideas in the literature on decompression theory suggest that this practice is desirable, but it has the effect of greatly extending already long decompressions to allow the slow-exchange kinetic terms to decay. Overall, we cannot claim any great confidence that the tables from Model 5 will be safer or more efficient; only experiments can answer the question.

Tables for 1% and 5% p(DCS) are presented in the appendices. The tables are thought to be optimum within 1 min, a finer precision than that of the no-decompression limits in Appendix 1 in which many 5 min intervals were used. The maximum values of p(DCS) are 1.1 and 5.1%, respectively; most predictions are closer to the nominal values. In general, they reveal that a long dive carries a much greater decompression time requirement to achieve similar levels of risk than a shorter dive. Examples of how these tables compare to present Navy practice are shown in Figs. 7-9. These figures plot the total decompression time against bottom time for three dive depths: 60, 140, and 250 ft. In each case there is a narrow range of short dives for which present Navy schedules are both fast and safe. According to our analysis divers could safely decompress even faster after these very short dives. With only

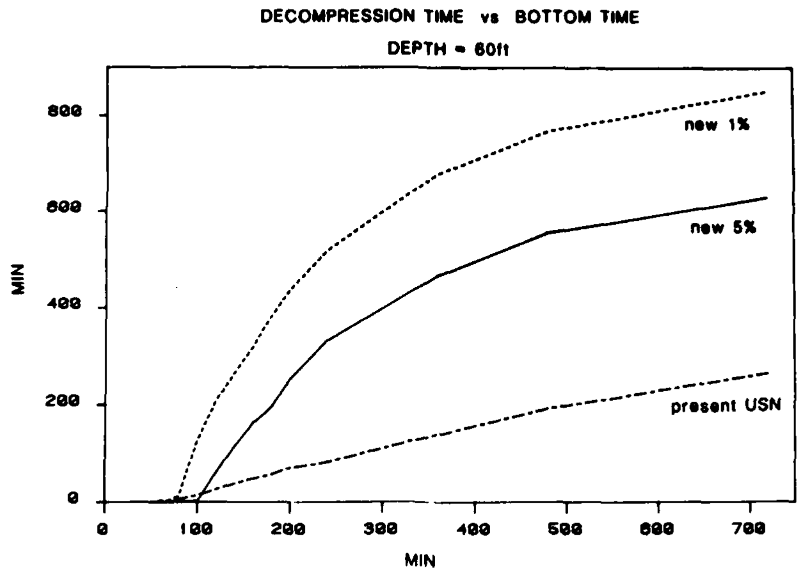

Fig. 7. Comparison of total decompression time (plotted vertically) against bottom time (plotted horizontally) according to three sets of tables for various dives to 60 ft. For comparison, the proposed decompression from saturation (very long bottom time) in a chamber treatment scenario requires more than 2000 min of decompression (E. Thalmann, private communication, 1984).

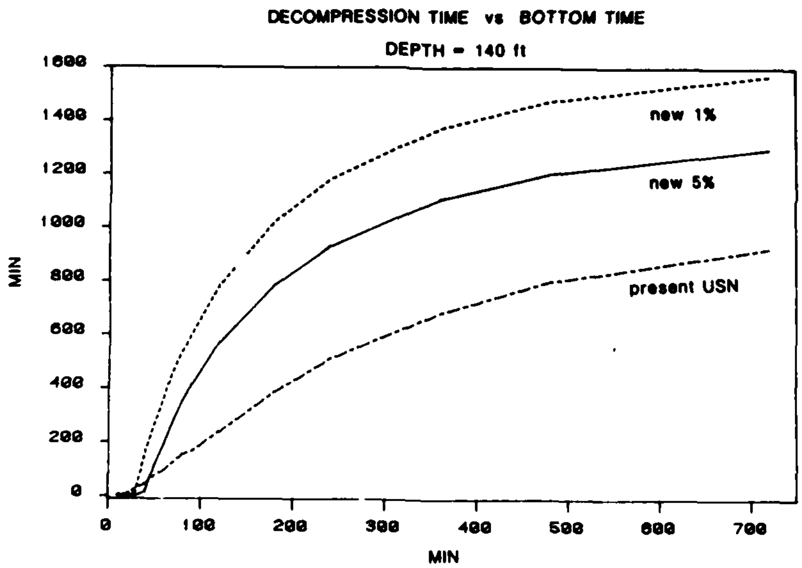

Fig. 8. Comparison of total decompression time (plotted vertically) against bottom time (plotted horizontally) according to three sets of tables for various dives to 140 ft.

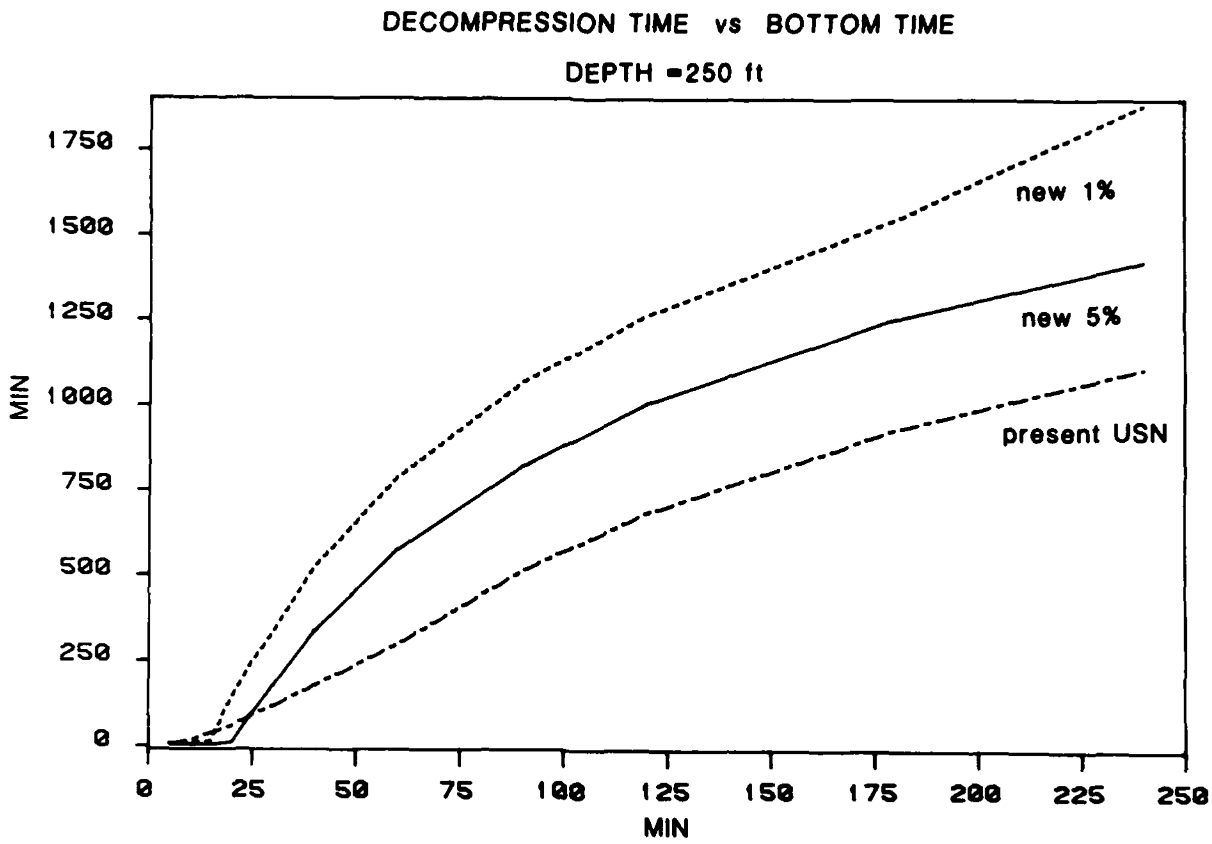

Fig. 9. Comparison of total decompression time (plotted vertically) against bottom time (plotted horizontally) according to three sets of tables for various dives to 250 ft.

slightly longer dives, however, present USN practice allows decompression faster than predicted for the predicted safety levels of 1% or 5% p(DCS). To achieve safe, long dives, much more decompression is required. In many cases, the time required is many hours longer than allowed presently.

Decompression tables of longer duration are not a new idea. Nearly 20 years ago the British calculated and partially tested long air tables, but they were not accepted for fleet use (Hempleman and Taylor, 1973). Very recently Canada extended the decompression time for air dives (Nishi and Lauckner, 1984). Recent calculation by proprietary methods has also produced longer decompression requirements (Edel, 1982).

DISCUSSION

These decompression tables are the first calculated in which the risk of incurring DCS is explicitly used. As discussed in the previous report this work is only a first approximation of statistically-based table design, and it suffers from many limitations. Nonmechanistic models were used, so the tables do not rest on calculations that embody the underlying basis of the disease. The data used in calibrating the models were extensive but still insufficient to allow very precise parameter estimation. In particular, the data did not include dives similar to the proposed new decompression schedules because they require so much decompression time. There were also indications that the data were not entirely consistent. Finally, the data were obtained during an earlier era when mild bends symptoms were ignored frequently. Thus, the new tables are substantial extrapolations to procedures that require testing.

Two aspects of these tables are already troubling. First is the abbreviated decompression required for very deep yet short dives. This recommendation is not compatible with the nearly 10% incidence of DCS found when the longer USN schedules were used for short 285 ft dives in a partially

documented Navy School, Diving, and Salvage report (Bayne et al., 1979). The second is the sudden decompression to shallow decompression stops that needs testing to ensure such a practice does not cause problems. Some data that address these points may be avaliable soon when present trials at the Navy Experimental Diving Unit (NEDU) and the Defence Civil Institute of Environmental Medicine (DCIEM) are completed (R.Y. Nishi and E.D. Thalmann, private communications, 1984). Real improvement in prediction performance can be expected when these problems are addressed more thoroughly.

At this time, we have two sets of tables designed to reduce DCS incidence to 1% or 5%. Choice of either, or of another risk level entirely, must be made with many other operational constraints in mind. The choice is somewhat clearer in Figs. 10 and 11 where the total in-water time is presented for all combinations of depth and useful bottom time. The extremely long times required for many dives make these exposures impractical for simple diving operations. The long dives would be more feasible with provision for chamber decompression. This 1-5% region of safety seems attainable, however. Hopes to achieve a safety level of only 0.1% or less incidence of DCS, as sought for other occupational hazards, must be viewed as unrealistic unless diving is curtailed substantially from the way it is practiced currently.

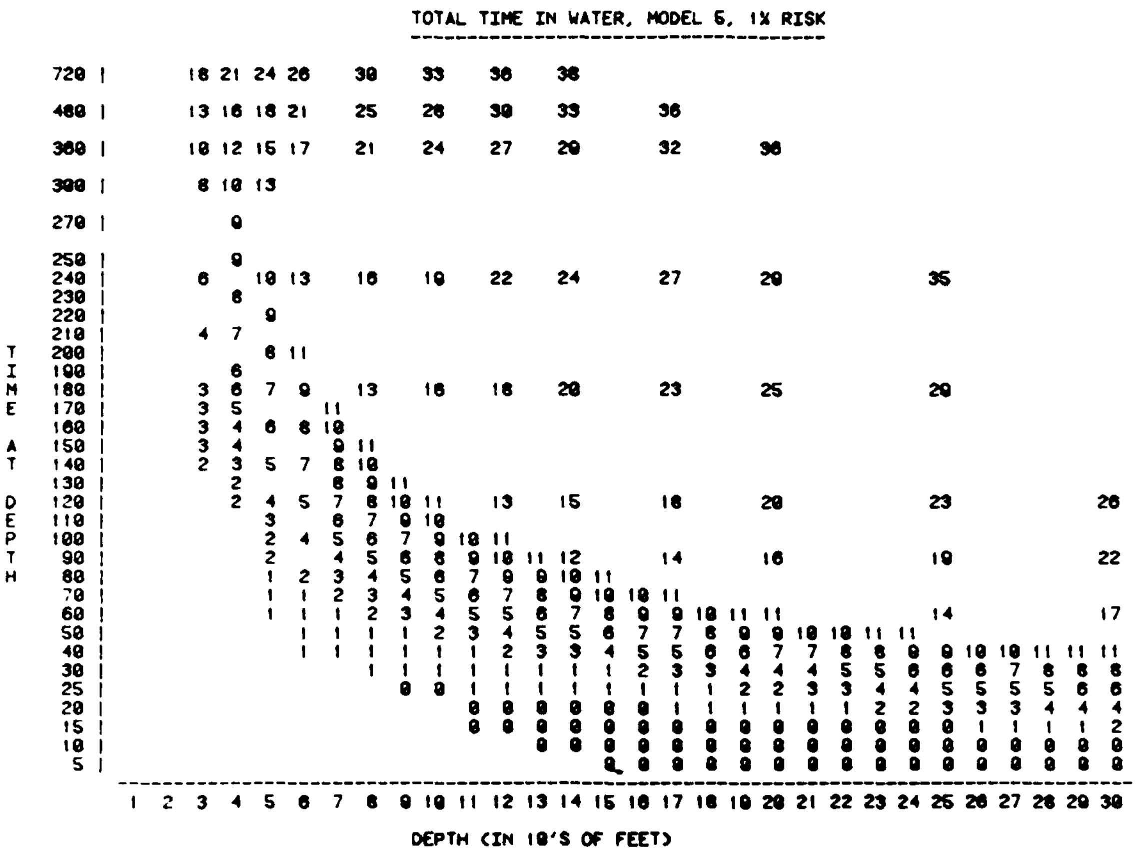

Fig. 10. Total in-water time for new tables of 1% p(DCS). Each symbol represents total time in h.

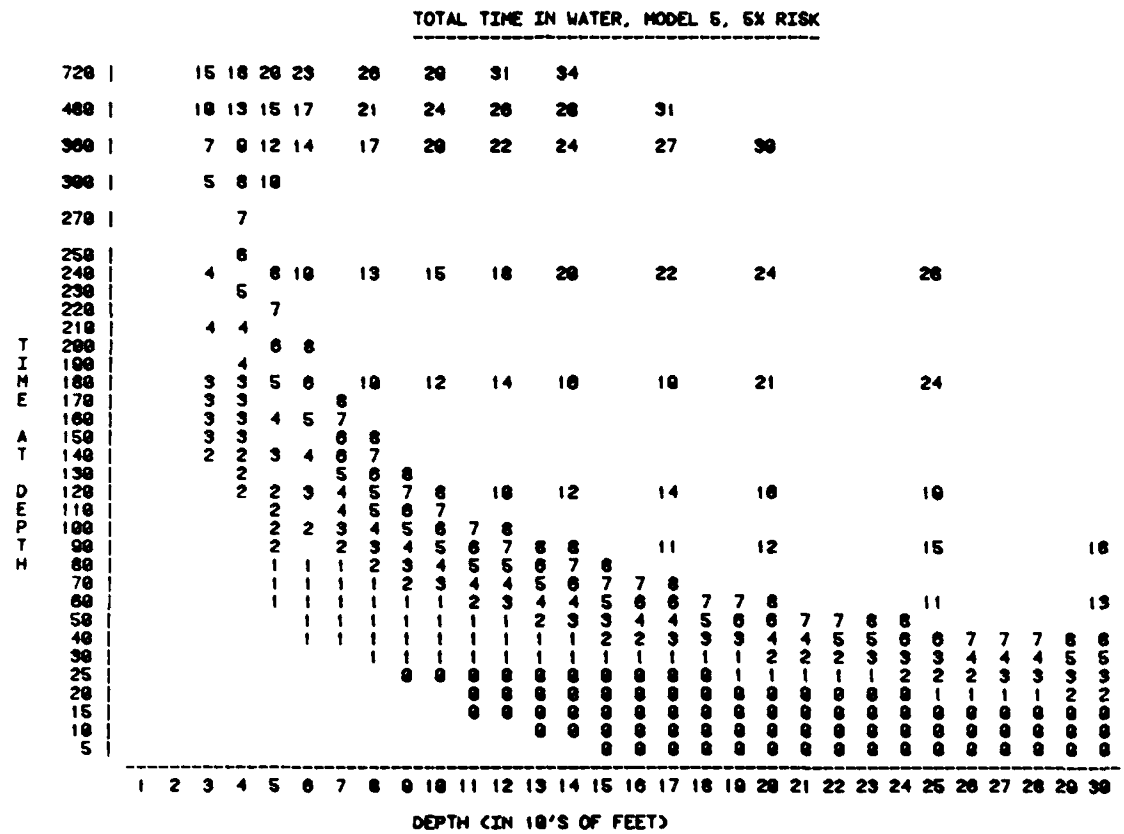

Fig. 11. Total in-water time for new tables of 5% p(DCS). Each symbol represents total time in h.

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Calculated No-decompression Limits*

Depth (fsw)	Model 3 .5	Model 3 1.0	Model 3 5.0	Model 4 .5	Model 4 1.0	Model 4 5.0	Model 5 .5	Model 5 1.0	Model 5 5.0
	Probability of DCS(%)								
30	160	180	290	200	220	320	120	170	270
35	130	140	230	160	170	240	85	130	200
40	110	120	190	130	140	190	60	100	170
50	80	90	140	10	100	140	30	65	120
60	7	75	110	7	25	110	15	40	95
70	4	60	95	5	10	90	7	25	80
80	3	50	80	4	7	75	5	15	65
90	2	40	70	4	5	65	5	10	55
100	2	15	60	3	5	55	4	8	50
110	2	5	55	3	5	50	3	7	45
120	-	4	50	-	4	45	3	5	40
130	-	4	45	-	4	40	3	5	35
140	-	3	40	-	3	35	-	4	30
150	-	3	35	-	3	30	-	4	30
160	-	3	35	-	3	30	-	3	25
170	-	-	32	-	-	25	-	3	25
180	-	-	31	-	-	25	-	3	23
190	-	-	29	-	-	21	-	3	21
200	-	-	27	-	-	18	-	-	20

*Time is in min.
Descent rate of 75 ft/min.
Ascent rate of 60 ft/min.
Descent time counts as part of bottom time.

Optimizing Search Algorithm

I. Internal Search. Given total decompression time and the number of stops, find the time allotment at which the minimum p(DCS) occurs.

  A. Perform gradient (coarse) search.

    1. Initialize search:

      a. Step size = total decompression time/(2 x number of stops).

      b. Allocate all of time at shallowest stop.

    2. Obtain p(DCS) from model and update minimum, if indicated.

    3. Calculate gradients and update time allotments using step size.

      a. For each stop, time at stop = time at stop + 1.

      b. Obtain p(DCS) from model and record whether or not an improvement was achieved.

      c. If p(DCS) improved, time at stop - time at stop + step size; otherwise, time at stop = time at stop - step size.

    4. If new time allotment was tried before at this step size, step size = step size/2. Start next search from minimum for old step size.

    5. If step size > 0, repeat from step 2.

  B. Perform fine search, starting at minimum from gradient search.

    1. Adjust times at stops pairwise by ± 1. Obtain p(DCS) from model and update minimum, if indicated.

    2. Repeat step 1 until an entire cycle (all possible combinations of pairs) has been completed with no change in minimum.

II. External search. Given the number of stops, an initial guess of decompression time, and a goal p(DCS), find the decompression time at which the goal p(DCS) occurs.

A. Interpolate or extrapolate from best time guesses until goal p(DCS) is found or duplicate time guess is obtained.

1. Obtain p(DCS) from model for no-decompression time. If p(DCS) < goal p(DCS), quit.

2. Obtain p(DCS) from internal search for current guess of decompression time. If p(DCS) = goal p(DCS) ± an acceptable tolerance, quit.

3. Obtain new time guess by interpolating or extrapolating line using logs of 2 time guesses nearest goal p(DCS).

4. If new time guess was not tried, repeat from step 2; otherwise, go to step B.

B. If duplicate time guess is obtained:

1. Augment time guess by 1 in direction of goal p(DCS).

2. If goal is found, quit.

3. If goal is passed, quit, reporting time whose p(DCS) is closest to goal p(DCS).

4. Otherwise, repeat step 1.

Appendix 3

Air Decompression Table for 5% Incidence of DCS
UNTESTED

Depth (fsw)	Bot. Time (min)	Time to First Stop (m:s)	Decompression Stops (fsw) Stop Times (min) 100	90	80	70	60	50	40	30	20	10	Total Ascent Time (m:s)
30	240	0:30										0	0:30
30	300	0:20										18	18:30
30	360	0:20										66	66:30
30	480	0:10									1	122	123:30
30	720	0:10									4	171	175:30
40	170	0:40										0	0:40
40	180	0:30										7	7:40
40	190	0:20									1	22	23:40
40	210	0:20									2	56	58:40
40	230	0:20									2	85	87:40
40	250	0:20									3	108	111:40
40	270	0:20									4	129	133:40
40	300	0:20									5	155	160:40
40	360	0:20									9	198	207:40
40	480	0:20									63	226	289:40
40	720	0:10								1	131	227	359:40
50	120	0:50										0	0:50
50	140	0:30									2	24	26:50
50	160	0:30									3	74	77:50
50	180	0:30									5	111	116:50
50	200	0:30									6	144	150:50
50	220	0:30									8	171	179:50

Model 5, Param. ABCD, NMRI 11/84

Appendix 3

Air Decompression Table for 5% Incidence of DCS
UNTESTED

Depth (fsw)	Bot. Time (min)	Time to First Stop (m:s)	Decompression Stops (fsw) Stop Times (min) 100	90	80	70	60	50	40	30	20	10	Total Ascent Time (m:s)
50	240	0:30									10	199	209:50
50	300	0:20								1	70	227	298:50
50	360	0:20								3	126	227	356:50
50	480	0:20								7	189	229	425:50
50	720	0:20								43	225	235	503:50
60	80	1:00										0	1:00
60	100	0:40									1	1	3:00
60	120	0:40									4	55	60:00
60	140	0:40									6	110	117:00
60	160	0:40									8	155	164:00
60	180	0:30								1	10	195	207:00
60	200	0:30								1	27	226	255:00
60	240	0:30								3	103	227	334:00
60	360	0:30								14	219	234	468:00
60	480	0:20							3	92	225	236	557:00
60	720	0:20							7	158	226	238	630:00
70	80	1:10										0	1:10
70	90	0:50									4	15	20:10
70	100	0:50									5	59	65:10
70	110	0:50									6	95	102:10
70	120	0:40								1	6	127	135:10
70	130	0:40								1	8	154	164:10

Model 5, Param. ABCD, NMRI 11/84

Air Decompression Table for 1% Incidence of DCS
UNTESTED

Depth (fsw)	Bot. Time (min)	Time to First Stop (m:s)	100	90	80	70	60	50	40	30	20	10	Total Ascent Time (m:s)
			Decompression Stops (fsw) Stop Times (min)										
80	120	0:50								4	26	340	371:20
80	130	0:50								4	76	341	422:20
80	140	0:50								6	115	341	463:20
80	150	0:50								7	149	341	498:20
80	180	0:40							2	12	224	343	582:20
80	240	0:40							6	108	265	351	731:20
80	360	0:30						3	67	209	268	356	904:20
80	480	0:30						12	148	210	267	357	995:20
80	720	0:20					3	75	174	210	269	359	1091:20
90	10	1:30										0	1:30
90	15	1:00									1	0	2:30
90	20	1:00									1	0	2:30
90	30	1:10									2	0	3:30
90	40	1:10									2	2	5:30
90	50	1:10									4	8	13:30
90	60	1:00								1	5	105	112:30
90	70	1:00								2	6	179	188:30
90	80	1:00								2	9	234	246:30
90	90	1:00								3	11	281	296:30
90	100	1:00								4	16	328	349:30
90	110	1:00								5	65	341	412:30

Model 5, Param. ABCD, NMRI 10/84

Air Decompression Table for 1% Incidence of DCS
UNTESTED

Depth (fsw)	Bot. Time (min)	Time to First Stop (m:s)	Decompression Stops (fsw) Stop Times (min) 100	90	80	70	60	50	40	30	20	10	Total Ascent Time (m:s)
70	80	0:50									5	103	109:10
70	90	0:50									6	159	166:10
70	100	0:40								1	7	203	212:10
70	110	0:40								1	9	240	251:10
70	120	0:40								2	11	272	286:10
70	130	0:40								2	13	304	320:10
70	140	0:40								3	19	336	359:10
70	150	0:40								3	57	341	402:10
70	160	0:40								4	92	341	438:10
70	170	0:40								5	122	341	469:10
80	15	1:20										0	1:20
80	20	1:00									1	0	2:20
80	30	1:00									1	0	2:20
80	40	1:00									2	0	3:20
80	50	1:00									2	2	5:20
80	60	1:00									4	30	35:20
80	70	0:50								1	5	115	122:20
80	80	0:50								1	7	176	185:20
80	90	0:50								2	8	225	236:20
80	100	0:50								2	11	266	280:20
80	110	0:50								3	13	305	322:20

Model 5, Param. ABCD, NMRI 10/84

Appendix 4

Air Decompression Table for 1% Incidence of DCS
UNTESTED

Depth (fsw)	Bot. Time (min)	Time to First Stop (m:s)	Decompression Stops (fsw) Stop Times (min) 100	90	80	70	60	50	40	30	20	10	Total Ascent Time (m:s)
50	720	0:20								97	265	351	713:50
60	40	1:00										0	1:00
60	50	1:00										1	2:00
60	60	0:40									1	1	3:00
60	70	0:40									1	2	4:00
60	80	0:40									2	10	13:00
60	100	0:40									4	123	128:00
60	120	0:40									7	199	207:00
60	140	0:40									10	256	267:00
60	160	0:30								1	13	305	320:00
60	180	0:30								2	39	341	383:00
60	200	0:30								3	94	341	439:00
60	240	0:30								6	170	342	519:00
60	360	0:20							1	60	265	351	678:00
60	480	0:20							6	145	265	351	768:00
60	720	0:20							21	207	267	355	851:00
70	25	1:10										0	1:10
70	30	1:00										1	2:10
70	40	0:50									1	0	2:10
70	50	0:50									1	1	3:10
70	60	0:50									2	2	5:10
70	70	0:50									4	30	35:10

Model 5, Param. ABCD, NMRI 10/84

Air Decompression Table for 1% Incidence of DCS
UNTESTED

Depth (fsw)	Bot. Time (min)	Time to First Stop (m:s)	100	90	80	70	60	50	40	30	20	10	Total Ascent Time (m:s)
			Decompression Stops (fsw) Stop Times (min)										
40	250	0:20									7	253	260:40
40	270	0:20									9	274	283:40
40	300	0:20									11	305	316:40
40	360	0:20									43	341	384:40
40	480	0:20									131	342	473:40
40	720	0:10								5	198	342	545:40
50	70	0:50										0	0:50
50	80	0:40										1	1:50
50	90	0:40										3	3:50
50	100	0:30									1	11	12:50
50	110	0:30									2	60	62:50
50	120	0:30									3	102	105:50
50	140	0:30									5	167	172:50
50	160	0:30									7	216	223:50
50	180	0:30									9	256	265:50
50	200	0:30									12	291	303:50
50	220	0:30									16	326	342:50
50	240	0:20								1	44	341	386:50
50	300	0:20								3	138	342	483:50
50	360	0:20								7	193	342	542:50
50	480	0:20								16	257	349	622:50

Model 5, Param. ABCD, NMRI 10/84

Air Decompression Table for 1% Incidence of DCS
UNTESTED

Depth (fsw)	Bot. Time (min)	Time to First Stop (m:s)	100	90	80	70	60	50	40	30	20	10	Total Ascent Time (m:s)
			Decompression Stops (fsw) Stop Times (min)										
30	170	0:30										0	0:30
30	180	0:20										1	1:30
30	210	0:20										35	35:30
30	240	0:20										90	90:30
30	300	0:10									1	163	164:30
30	360	0:10									3	210	213:30
30	480	0:10									6	267	273:30
30	720	0:10									12	326	338:30
40	100	0:40										0	0:40
40	110	0:30										1	1:40
40	120	0:30										2	2:40
40	130	0:30										7	7:40
40	140	0:20									1	36	37:40
40	150	0:20									1	70	71:40
40	160	0:20									2	99	101:40
40	170	0:20									2	125	127:40
40	180	0:20									3	147	150:40
40	190	0:20									3	167	170:40
40	210	0:20									5	200	205:40
40	230	0:20									6	228	234:40

Model 5, Param. ABCD, NMRI 10/84

Air Decompression Table for 5% Incidence of DCS
UNTESTED

Depth (fsw)	Bot. Time (min)	Time to First Stop (m:s)	Decompression Stops (fsw) Stop Times (min) 100	90	80	70	60	50	40	30	20	10	Total Ascent Time (m:s)
280	10	4:40										0	4:40
280	15	3:50						2	0	0	0	0	6:40
280	20	3:50						1	2	2	5	37	51:40
280	25	3:40					1	1	2	3	7	132	150:40
280	30	3:40					1	1	2	4	12	211	235:40
280	40	3:30				1	1	2	3	7	160	227	405:40
290	10	4:50										0	4:50
290	15	4:00						1	1	0	0	0	6:50
290	20	4:00						1	2	2	5	55	69:50
290	25	3:50					1	1	2	3	7	149	167:50
290	30	3:50					1	2	2	4	22	226	261:50
290	40	3:40				1	1	2	3	8	178	228	425:50
300	10	5:00										0	5:00
300	15	4:10						1	1	1	0	0	8:00
300	20	4:00					1	1	1	3	5	71	87:00
300	25	4:00					1	1	2	3	8	163	183:00
300	30	4:00					1	2	2	4	45	227	286:00
300	40	3:50				1	1	2	4	9	194	230	446:00
300	60	3:40			1	2	2	4	37	183	227	242	703:00
300	90	3:20	1	1	2	4	12	124	154	185	230	249	967:00
300	120	3:20	3	3	7	65	116	132	155	186	231	252	1155:00

Air Decompression Table for 5% Incidence of DCS
UNTESTED

Depth (fsw)	Bot. Time (min)	Time to First Stop (m:s)	100	90	80	70	60	50	40	30	20	10	Total Ascent Time (m:s)
			Decompression Stops (fsw) Stop Times (min)										
250	15	4:00										0	4:10
250	20	3:20						1	1	2	3	0	11:10
250	25	3:20						1	2	2	6	81	96:10
250	30	3:10					1	1	2	3	8	156	175:10
250	40	3:10					1	2	2	5	96	227	337:10
250	60	3:00				1	2	2	6	97	226	236	574:10
250	90	2:50			2	2	4	11	144	184	228	244	823:10
250	120	2:30	1	1	3	5	43	132	154	185	230	248	1006:10
250	180	2:30	5	7	58	103	116	133	155	186	233	255	1255:10
250	240	2:30	44	85	93	104	117	134	156	188	236	265	1426:10
260	15	4:10										0	4:20
260	20	3:30						1	1	2	4	4	16:20
260	25	3:30						1	2	3	6	99	115:20
260	30	3:20					1	1	2	3	9	173	193:20
260	40	3:20					1	2	2	6	118	228	361:20
270	10	4:30										0	4:30
270	15	3:40						1	0	0	0	0	5:30
270	20	3:40						1	2	2	4	19	32:30
270	25	3:30					1	1	1	3	6	117	133:30
270	30	3:30					1	1	2	3	10	192	213:30
270	40	3:30					2	1	3	6	140	228	384:30

Model 5, Param. ABCD, NMRI 11/84

Air Decompression Table for 5% Incidence of DCS
UNTESTED

Depth (fsw)	Bot. Time (min)	Time to First Stop (m:s)	100	90	80	70	60	50	40	30	20	10	Total Ascent Time (m:s)
			Decompression Stops (fsw) Stop Times (min)										
210	30	2:40						1	1	3	5	77	90:30
210	40	2:40						1	2	4	10	197	217:30
210	50	2:30					1	1	3	5	112	227	352:30
220	15	3:40										0	3:40
220	20	3:00							1	0	0	0	4:40
220	25	2:50						1	1	2	5	18	30:40
220	30	2:50						1	2	2	6	99	113:40
220	40	2:50						2	2	3	17	221	248:40
220	50	2:40					1	2	2	7	138	227	380:40
230	15	3:50										0	3:50
230	20	3:10							1	2	0	0	6:50
230	25	3:00						1	1	3	4	41	53:50
230	30	3:00						1	2	3	6	119	134:50
230	40	2:50					1	1	2	4	42	227	280:50
230	50	2:50					1	2	3	7	162	228	406:50
240	15	4:00										0	4:00
240	20	3:20							2	1	1	0	8:00
240	25	3:10						1	2	2	5	62	76:00
240	30	3:10						1	2	3	7	138	155:00
240	40	3:00					1	1	3	4	71	227	311:00
240	50	3:00					2	1	4	8	184	229	432:00

Model 5, Param. ABCD, NMRI 11/84

Air Decompression Table for 5% Incidence of DCS
UNTESTED

Depth (fsw)	Bot. Time (min)	Time to First Stop (m:s)	100	90	80	70	60	50	40	30	20	10	Total Ascent Time (m:s)
			Decompression Stops (fsw) Stop Times (min)										
180	50	2:10						1	2	4	16	221	247:00
180	60	2:10						2	2	6	116	227	356:00
190	20	3:10										0	3:10
190	25	2:30							1	1	0	0	5:10
190	30	2:30							2	2	4	29	40:10
190	40	2:20						1	2	3	7	150	166:10
190	50	2:20						1	2	5	48	227	286:10
190	60	2:20						2	3	7	146	227	388:10
200	20	3:20										0	3:20
200	25	2:40							1	2	2	0	8:20
200	30	2:40							2	2	5	54	66:20
200	40	2:30						1	2	3	9	173	191:20
200	50	2:30						2	2	5	82	227	321:20
200	60	2:20					1	2	3	8	173	228	418:20
200	90	2:10				1	2	4	11	169	226	239	655:20
200	120	2:00			1	2	4	14	148	184	229	244	829:20
200	180	1:50		2	3	10	97	132	154	185	230	250	1066:20
200	240	1:40	3	5	34	103	116	132	155	186	231	253	1221:20
200	360	1:40	42	85	93	104	116	134	156	187	235	261	1416:20
210	15	3:30										0	3:30
210	20	3:00								1	0	0	4:30
210	25	2:50							2	2	3	3	13:30

Model 5, Param. ABCD, NMRI 11/84

Appendix 3

Air Decompression Table for 5% Incidence of DCS
UNTESTED

Depth (fsw)	Bot. Time (min)	Time to First Stop (m:s)	100	90	80	70	60	50	40	30	20	10	Total Ascent Time (m:s)
			Decompression Stops (fsw) Stop Times (min)										
160	25	2:40										0	2:40
160	30	2:10								1	0	0	3:40
160	40	2:00							1	3	5	72	83:40
160	50	2:00							2	3	8	163	178:40
160	60	1:50						1	2	4	42	227	278:40
160	70	1:50						1	3	6	125	227	364:40
170	25	2:50										0	2:50
170	30	2:10							1	1	2	0	6:50
170	40	2:10							2	2	6	101	113:50
170	50	2:00						1	2	3	10	192	210:50
170	60	2:00						1	2	5	82	227	319:50
170	70	2:00						2	3	7	158	228	400:50
170	90	1:50					1	2	5	73	225	236	544:50
170	120	1:40				1	2	5	48	183	227	241	709:50
170	180	1:30			1	4	9	107	154	184	229	246	936:50
170	240	1:20		2	4	14	112	132	154	185	231	250	1086:50
170	360	1:10	4	9	76	103	116	132	155	186	231	253	1267:50
170	480	1:10	14	77	93	103	116	133	155	187	233	257	1370:50
180	20	2:50										0	3:00
180	25	2:30								1	0	0	4:00
180	30	2:20							1	2	4	5	15:00
180	40	2:20							2	3	7	126	141:00

Model 5, Param. ABCD, NMRI 11/84

Air Decompression Table for 5% Incidence of DCS
UNTESTED

Depth (fsw)	Bot. Time (min)	Time to First Stop (m:s)	100	90	80	70	60	50	40	30	20	10	Total Ascent Time (m:s)
			Decompression Stops (fsw) Stop Times (min)										
130	70	1:30							1	4	12	206	225:10
130	80	1:30							2	5	69	227	305:10
130	90	1:30							3	6	129	227	367:10
140	30	2:20										0	2:20
140	40	1:50								2	4	8	16:20
140	50	1:40							1	3	6	103	115:20
140	60	1:40							2	3	9	175	191:20
140	70	1:40							2	4	43	227	278:20
140	80	1:30						1	2	6	115	227	353:20
140	90	1:30						1	3	8	169	228	411:20
140	120	1:30						3	6	99	225	236	571:20
140	180	1:20					4	8	120	183	228	242	787:20
140	240	1:10				3	9	104	154	184	229	246	931:20
140	360	1:00			5	32	116	132	155	185	231	250	1108:20
140	480	0:50		4	24	103	116	132	155	185	232	252	1205:20
140	720	0:40	3	21	92	103	116	133	155	186	232	254	1297:20
150	30	2:30										0	2:30
150	40	1:50							1	2	5	41	51:30
150	50	1:50							1	3	7	135	148:30
150	60	1:50							2	4	12	211	231:30
150	70	1:40						1	2	5	87	227	324:30
150	80	1:40						1	3	7	153	228	394:30

Model 5, Param. ABCD, NMRI 11/84

Air Decompression Table for 5% Incidence of DCS
UNTESTED

Depth (fsw)	Bot. Time (min)	Time to First Stop (m:s)	100	90	80	70	60	50	40	30	20	10	Total Ascent Time (m:s)
			Decompression Stops (fsw) Stop Times (min)										
110	60	1:20								2	5	67	75:50
110	70	1:20								3	7	128	139:50
110	80	1:20								4	9	180	194:50
110	90	1:10							1	4	24	226	256:50
110	100	1:10							1	5	82	227	316:50
120	40	2:00										0	2:00
120	50	1:30								2	5	30	39:00
120	60	1:30								3	6	107	118:00
120	70	1:20							1	3	8	167	181:00
120	80	1:20							1	4	18	223	248:00
120	90	1:20							2	5	81	227	317:00
120	100	1:20							3	6	133	227	371:00
120	120	1:10						1	3	11	209	232	458:00
120	180	1:10						4	17	180	227	241	671:00
120	240	1:00					3	11	140	184	228	243	811:00
120	360	0:50				4	30	132	154	184	230	248	984:00
120	480	0:40			2	13	110	132	154	185	231	250	1079:00
120	720	0:30		1	9	86	116	133	154	186	231	251	1169:00
130	30	2:10										0	2:10
130	40	1:40								1	2	0	5:10
130	50	1:40								3	5	69	79:10
130	60	1:30							1	3	7	143	156:10

Model 5, Param. ABCD, NMRI 11/84

Air Decompression Table for 5% Incidence of DCS
UNTESTED

Depth (fsw)	Bot. Time (min)	Time to First Stop (m:s)	Decompression Stops (fsw) Stop Times (min) 100	90	80	70	60	50	40	30	20	10	Total Ascent Time (m:s)
90	80	1:00								1	6	90	98:30
90	90	1:00								2	7	134	144:30
90	100	1:00								3	8	173	185:30
90	110	1:00								3	13	212	229:30
90	120	1:00								4	47	227	279:30
90	130	1:00								5	87	227	320:30
100	50	1:40										0	1:40
100	60	1:10								1	4	20	26:40
100	70	1:10								2	5	86	94:40
100	80	1:10								3	7	136	147:40
100	90	1:10								3	9	182	195:40
100	100	1:10								4	20	225	250:40
100	110	1:00							1	4	71	227	304:40
100	120	1:00							1	6	113	227	348:40
100	180	0:50						1	5	78	225	235	545:40
100	240	0:50						3	21	182	227	241	675:40
100	360	0:40					3	26	153	184	229	245	841:40
100	480	0:30				1	9	109	154	184	229	246	933:40
100	720	0:30				5	66	132	154	185	230	249	1022:40
110	40	1:50										0	1:50
110	50	1:20								1	3	1	6:50

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Appendix 3

Air Decompression Table for 5% Incidence of DCS
UNTESTED

Depth (fsw)	Bot. Time (min)	Time to First Stop (m:s)	Decompression Stops (fsw) Stop Times (min) 100	90	80	70	60	50	40	30	20	10	Total Ascent Time (m:s)
70	140	0:40								1	9	181	192:10
70	150	0:40								2	12	206	221:10
70	160	0:40								2	25	226	254:10
70	170	0:40								3	55	226	285:10
80	60	1:20										0	1:20
80	70	1:00									2	0	3:20
80	80	1:00									5	32	38:20
80	90	0:50								1	5	81	88:20
80	100	0:50								1	7	122	131:20
80	110	0:50								2	8	154	165:20
80	120	0:50								2	10	187	200:20
80	130	0:50								3	15	220	239:20
80	140	0:50								4	48	226	279:20
80	150	0:50								5	81	227	314:20
80	180	0:40							1	7	157	228	394:20
80	240	0:40							4	55	225	235	520:20
80	360	0:30						2	20	182	227	241	673:20
80	480	0:30						6	104	183	227	242	763:20
80	720	0:20					1	33	153	184	229	245	846:20
90	50	1:30										0	1:30
90	60	1:10									1	0	2:30
90	70	1:00								1	4	34	40:30

Model 5, Param. ABCD, NMRI 11/84

Air Decompression Table for 1% Incidence of DCS
UNTESTED

Depth (fsw)	Bot. Time (min)	Time to First Stop (m:s)	100	90	80	70	60	50	40	30	20	10	Total Ascent Time (m:s)
			Decompression Stops (fsw) Stop Times (min)										
90	120	0:50							1	5	115	341	463:30
90	130	0:50							1	7	155	341	505:30
100	8	1:40										0	1:40
100	10	1:20									1	0	2:40
100	20	1:20									2	0	3:40
100	30	1:20									2	1	4:40
100	40	1:10								1	3	2	7:40
100	50	1:10								1	5	72	79:40
100	60	1:10								2	6	164	173:40
100	70	1:10								3	8	230	242:40
100	80	1:10								4	11	284	300:40
100	90	1:00							1	4	21	337	364:40
100	100	1:00							1	5	86	341	434:40
100	110	1:00							2	6	139	341	489:40
100	120	1:00							2	8	180	342	533:40
100	180	0:50						1	8	131	265	351	757:40
100	240	0:50						5	67	209	268	356	906:40
100	360	0:40					5	68	174	211	269	359	1087:40
100	480	0:30				1	20	145	174	211	270	361	1183:40
100	720	0:30				9	103	148	174	211	270	361	1277:40
110	7	1:50										0	1:50

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Appendix 4

Air Decompression Table for 1% Incidence of DCS
UNTESTED

Depth (fsw)	Bot. Time (min)	Time to First Stop (m:s)	100	90	80	70	60	50	40	30	20	10	Total Ascent Time (m:s)
			Decompression Stops (fsw) Stop Times (min)										
110	10	1:30									1	0	2:50
110	20	1:30									2	0	3:50
110	25	1:30									3	0	4:50
110	30	1:20								1	2	1	5:50
110	40	1:20								1	4	8	14:50
110	50	1:20								2	6	127	136:50
110	60	1:20								3	8	210	222:50
110	70	1:10							1	3	11	275	291:50
110	80	1:10							1	4	20	336	362:50
110	90	1:10							2	5	92	341	441:50
110	100	1:10							2	7	149	342	501:50
120	5	2:00										0	2:00
120	10	1:40									1	0	3:00
120	15	1:40									2	0	4:00
120	20	1:30								1	2	0	5:00
120	25	1:30								1	2	1	6:00
120	30	1:30								1	3	1	7:00
120	40	1:30								2	5	59	68:00
120	50	1:30								3	6	174	185:00
120	60	1:20							1	3	10	252	268:00
120	70	1:20							1	4	15	321	343:00

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Appendix 4

Air Decompression Table for 1% Incidence of DCS
UNTESTED

Depth (fsw)	Bot. Time (min)	Time to First Stop (m:s)	100	90	80	70	60	50	40	30	20	10	Total Ascent Time (m:s)
			Decompression Stops (fsw) Stop Times (min)										
120	80	1:20							2	5	83	341	433:00
120	90	1:20							3	6	150	341	502:00
120	100	1:20							3	10	200	343	558:00
120	120	1:10						1	5	41	265	351	665:00
120	180	1:00					1	5	61	209	267	356	901:00
120	240	1:00					4	35	174	211	269	359	1054:00
120	360	0:50				6	68	148	174	212	270	361	1241:00
120	480	0:40			3	40	129	148	175	212	271	362	1342:00
120	720	0:30		2	21	113	129	149	175	212	271	362	1436:00
130	5	2:10										0	2:10
130	10	1:50									2	0	4:10
130	15	1:40								1	2	0	5:10
130	20	1:40								1	2	1	6:10
130	25	1:40								1	3	1	7:10
130	30	1:40								2	3	2	9:10
130	40	1:40								3	5	108	118:10
130	50	1:30							1	3	8	213	227:10
130	60	1:30							2	3	12	291	310:10
130	70	1:30							2	5	57	341	407:10
130	80	1:30							3	6	137	341	489:10
130	90	1:20						1	3	9	197	342	554:10

Model 5, Param. ABCD, NMRI 10/84

Air Decompression Table for 1% Incidence of DCS
UNTESTED

Depth (fsw)	Bot. Time (min)	Time to First Stop (m:s)	Decompression Stops (fsw) Stop Times (min) 100	90	80	70	60	50	40	30	20	10	Total Ascent Time (m:s)
140	4	2:20										0	2:20
140	5	2:00									1	0	3:20
140	10	2:00									2	0	4:20
140	15	1:50								1	2	0	5:20
140	20	1:50								1	3	0	6:20
140	25	1:50								2	2	2	8:20
140	30	1:50								2	4	5	13:20
140	40	1:40							1	2	6	150	161:20
140	50	1:40							2	3	9	249	265:20
140	60	1:40							2	4	17	331	356:20
140	70	1:30						1	2	6	111	340	462:20
140	80	1:30						1	3	8	182	341	537:20
140	90	1:30						2	3	13	236	345	601:20
140	120	1:20					1	3	9	152	265	352	784:20
140	180	1:10				1	4	16	163	210	268	358	1022:20
140	240	1:00			1	3	18	143	174	211	270	360	1182:20
140	360	0:50		1	6	67	129	149	175	212	271	362	1374:20
140	480	0:50		6	55	114	129	149	175	212	271	363	1476:20
140	720	0:40	5	48	102	115	129	149	175	212	272	363	1572:20
150	4	2:30										0	2:30
150	5	2:10									1	0	3:30
150	10	2:10									3	0	5:30

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Appendix 4

Air Decompression Table for 1% Incidence of DCS
UNTESTED

Depth (fsw)	Bot. Time (min)	Time to First Stop (m:s)	100	90	80	70	60	50	40	30	20	10	Total Ascent Time (m:s)
			Decompression Stops (fsw) Stop Times (min)										
150	15	2:00								1	3	0	6:30
150	20	2:00								2	2	1	7:30
150	25	2:00								2	3	2	9:30
150	30	1:50							1	2	4	34	43:30
150	40	1:50							1	3	7	185	198:30
150	50	1:50							2	3	12	281	300:30
150	60	1:40						1	2	5	64	341	415:30
150	70	1:40						1	3	7	155	341	509:30
150	80	1:40						2	3	12	219	343	581:30
160	5	2:20									1	0	3:40
160	10	2:10								1	2	0	5:40
160	15	2:10								2	2	0	6:40
160	20	2:10								2	3	1	8:40
160	25	2:00							1	2	3	3	11:40
160	30	2:00							1	2	5	76	86:40
160	40	2:00							2	3	8	216	231:40
160	50	1:50						1	2	3	15	316	339:40
160	60	1:50						1	3	5	110	341	462:40
160	70	1:50						2	3	9	193	341	550:40
170	5	2:30									1	0	3:50
170	10	2:20								1	2	0	5:50

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Appendix 4

Air Decompression Table for 1% Incidence of DCS
UNTESTED

Depth (fsw)	Bot. Time (min)	Time to First Stop (m:s)	Decompression Stops (fsw) Stop Times (min) 100	90	80	70	60	50	40	30	20	10	Total Ascent Time (m:s)
170	15	2:20								2	2	1	7:50
170	20	2:10							1	1	3	2	9:50
170	25	2:10							1	2	4	10	19:50
170	30	2:10							1	3	5	112	123:50
170	40	2:10							2	3	10	246	263:50
170	50	2:00						1	2	4	34	341	384:50
170	60	2:00						2	2	7	149	341	503:50
170	70	2:00						2	4	12	225	344	589:50
170	90	1:50					1	3	7	127	265	352	757:50
170	120	1:40				1	3	6	96	209	268	356	941:50
170	180	1:30			2	4	18	145	174	211	270	360	1186:50
170	240	1:20		2	5	44	129	148	175	212	271	362	1350:50
170	360	1:10	4	19	100	115	129	149	175	213	272	364	1542:50
170	480	1:10	33	93	103	116	131	151	178	216	277	370	1670:50
180	4	3:00										0	3:00
180	5	2:40									2	0	5:00
180	10	2:30								2	2	0	7:00
180	15	2:20							1	1	3	0	8:00
180	20	2:20							1	2	2	2	10:00
180	25	2:20							1	2	5	44	55:00
180	30	2:20							2	2	6	144	157:00
180	40	2:10						1	2	3	11	273	293:00

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Air Decompression Table for 1% Incidence of DCS
UNTESTED

Depth (fsw)	Bot. Time (min)	Time to First Stop (m:s)	100	90	80	70	60	50	40	30	20	10	Total Ascent Time (m:s)
			Decompression Stops (fsw) Stop Times (min)										
180	50	2:10						1	3	5	79	342	433:00
180	60	2:10						2	3	8	183	342	541:00
190	5	2:50									2	0	5:10
190	10	2:40								2	2	0	7:10
190	15	2:30							1	2	2	1	9:10
190	20	2:30							1	2	3	3	12:10
190	25	2:30							2	2	5	79	91:10
190	30	2:20						1	1	3	6	174	188:10
190	40	2:20						1	2	4	13	299	322:10
190	50	2:20						2	2	6	117	341	471:10
190	60	2:10					1	2	3	11	213	342	575:10
200	5	2:50								1	1	0	5:20
200	10	2:40							1	1	2	0	7:20
200	15	2:40							1	2	2	1	9:20
200	20	2:40							1	2	4	4	14:20
200	25	2:30						1	1	2	5	111	123:20
200	30	2:30						1	2	2	8	198	214:20
200	40	2:30						2	2	4	16	329	356:20
200	50	2:20					1	1	3	7	150	341	506:20
200	60	2:20					1	2	4	14	240	346	610:20
200	90	2:10				1	3	4	39	209	268	356	883:20

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Air Decompression Table for 1% Incidence of DCS
UNTESTED

Depth (fsw)	Bot. Time (min)	Time to First Stop (m:s)	Decompression Stops (fsw) Stop Times (min) 100	90	80	70	60	50	40	30	20	10	Total Ascent Time (m:s)
200	120	2:00			1	3	4	50	174	211	269	360	1075:20
200	180	1:40	1	2	4	22	128	148	175	212	270	370	1327:20
200	240	1:40	3	7	65	114	130	149	175	213	272	363	1494:20
200	360	1:40	75	95	105	119	135	156	186	227	291	388	1780:20
210	5	3:00								1	1	0	5:30
210	10	2:50							1	1	3	0	8:30
210	15	2:50							1	2	3	1	10:30
210	20	2:50							2	2	4	12	23:30
210	25	2:40						1	1	3	5	138	151:30
210	30	2:40						1	2	3	8	222	239:30
210	40	2:40						2	2	4	44	342	397:30
210	50	2:30					1	2	3	8	179	341	537:30
220	5	3:10								1	1	0	5:40
220	10	3:00							1	1	3	0	8:40
220	15	3:00							1	2	3	1	10:40
220	20	2:50						1	1	2	5	42	54:40
220	25	2:50						1	2	2	6	163	177:40
220	30	2:50						1	2	3	9	244	262:40
220	40	2:40					1	1	2	5	80	342	434:40
220	50	2:40					1	2	3	10	205	342	566:40
230	5	3:20								1	2	0	6:50

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Air Decompression Table for 1% Incidence of DCS
UNTESTED

Depth (fsw)	Bot. Time (min)	Time to First Stop (m:s)	100	90	80	70	60	50	40	30	20	10	Total Ascent Time (m:s)
			Decompression Stops (fsw) Stop Times (min)										
230	10	3:10							1	2	2	0	8:50
230	15	3:10							2	1	3	2	11:50
230	20	3:00						1	1	2	5	72	84:50
230	25	3:00						1	2	3	6	186	201:50
230	30	3:00						2	2	3	10	266	286:50
230	40	2:50					1	2	2	6	110	341	465:50
230	50	2:50					2	2	3	13	229	344	596:50
240	5	3:30								1	2	0	7:00
240	10	3:20							1	2	2	0	9:00
240	15	3:10						1	1	2	3	2	13:00
240	20	3:10						1	2	2	5	97	111:00
240	25	3:10						1	2	3	7	207	224:00
240	30	3:00					1	1	2	3	12	286	309:00
240	40	3:00					1	2	2	7	138	341	495:00
240	50	2:50				1	1	2	4	16	252	347	627:00
250	5	3:40								1	2	0	7:10
250	10	3:30							1	2	2	1	10:10
250	15	3:20						1	1	2	3	3	14:10
250	20	3:20						1	2	2	5	122	136:10
250	25	3:10					1	1	2	3	8	227	246:10
250	30	3:10					1	1	2	4	13	307	332:10

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Air Decompression Table for 1% Incidence of DCS
UNTESTED

Depth (fsw)	Bot. Time (min)	Time to First Stop (m:s)	Decompression Stops (fsw) Stop Times (min) 100	90	80	70	60	50	40	30	20	10	Total Ascent Time (m:s)
250	40	3:10					2	1	3	7	164	341	522:10
250	60	3:00				2	1	3	9	151	265	351	786:10
250	90	2:40		1	1	2	5	41	174	211	269	359	1067:10
250	120	2:30	1	2	2	7	82	148	174	212	270	361	1263:10
250	180	2:30	6	10	90	115	131	151	178	216	276	369	1546:10
250	240	2:3	79	97	108	122	139	163	196	242	315	419	1884:10
260	5	3:50								1	2	0	7:20
260	10	3:40							1	2	2	1	10:20
260	15	3:30						1	1	2	3	5	16:20
260	20	3:30						1	2	2	6	144	159:20
260	25	3:20					1	1	2	3	9	244	264:20
260	30	3:20					1	1	2	4	17	330	359:20
260	40	3:10				1	1	2	3	9	187	341	548:20
270	5	4:00								2	1	0	7:30
270	10	3:40						1	1	1	3	0	10:30
270	15	3:40						1	1	2	4	10	22:30
270	20	3:30					1	1	1	3	6	164	180:30
270	25	3:30					1	1	2	3	10	262	283:30
270	30	3:30					1	2	2	4	35	342	390:30
270	40	3:20				1	1	2	3	10	208	342	571:30
280	5	4:10								2	1	0	7:40

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Air Decompression Table for 1% Incidence of DCS
UNTESTED

Depth (fsw)	Bot. Time (min)	Time to First Stop (m:s)	100	90	80	70	60	50	40	30	20	10	Total Ascent Time (m:s)
			Decompression Stops (fsw) Stop Times (min)										
280	10	3:50						1	1	2	2	1	11:40
280	15	3:50						1	2	2	4	29	42:40
280	20	3:40					1	1	2	2	7	182	199:40
280	25	3:40					1	1	2	4	11	279	302:40
280	30	3:40					1	2	2	5	64	342	420:40
280	40	3:30				1	1	2	4	12	226	344	594:40
290	5	4:10							1	1	2	0	8:50
290	10	4:00						1	1	2	2	1	11:50
290	15	4:00						1	2	2	4	54	67:50
290	20	3:50					1	1	2	2	8	199	217:50
290	25	3:50					1	2	2	3	13	297	322:50
290	30	3:40				1	1	1	3	5	91	341	447:50
290	40	3:40				1	2	2	3	15	246	347	620:50
300	5	4:20							1	1	2	0	9:00
300	10	4:10						1	1	2	2	1	12:00
300	15	4:00					1	1	1	2	5	76	91:00
300	20	4:00					1	1	2	3	8	216	236:00
300	25	4:00					1	2	2	4	14	317	345:00
300	30	3:50				1	1	1	3	5	115	342	473:00
300	40	3:40			1	1	1	2	4	22	262	351	649:00
300	60	3:30		1	1	1	3	6	85	209	267	356	934:00

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Appendix 4

Air Decompression Table for 1% Incidence of DCS
UNTESTED

Depth (fsw)	Bot. Time (min)	Time to First Stop (m:s)	100	90	80	70	60	50	40	30	20	10	Total Ascent Time (m:s)
			Decompression Stops (fsw) Stop Times (min)										
300	90	3:20	1	2	2	4	41	148	174	211	270	361	1219:00
300	120	3:20	4	3	11	99	130	150	177	214	274	366	1433:00

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END

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